Active Learning Technologies and Student Motivation in STEM Education

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***Abstract*—In the digital era, maintaining student motivation in STEM education presents a significant challenge, necessitating innovative pedagogical approaches. This study aims to quantitatively evaluate the impact of specific active learning technologies on student motivation. The research focuses on four technological interventions: Virtual Reality Based Learning (VRL), Simulation Based Learning (SL), Gamification Learning (GL), and Mobile App Based Learning (MAL). A quantitative research design was employed, involving 150 undergraduate students from diverse Indonesian universities. Data were collected through online surveys with validated instruments (Cronbach's α >0.7) and analyzed using regression analysis to assess the relationship between technology use and self reported motivation. The findings demonstrate a significant positive impact of these technologies on student motivation. Regression analysis indicated that SL ($R^2 = 0.534$, GL ($R2 = 0.502$, and MAL ($R^2 = 0.487$ were substantial predictors of variance in student motivation. This research concludes that the integration of active learning technologies is a robust strategy for enhancing student motivation in STEM fields. The findings provide empirical evidence for educators and curriculum developers on the efficacy of using simulations, gamification, and mobile learning to create more engaging and effective educational environments, thereby addressing key challenges in contemporary digital pedagogy.**

***Keywords*—Student Motivation, STEM Education, Active Learning Technologies, Virtual Reality Based Learning (VRL)**

I. Introduction

In the digital era, maintaining student interest and engagement in learning is a significant challenge due to the widespread use of digital devices and technological advancements that often lead to disengagement with traditional methods [1]. This paper proposes active learning as a solution, promoting student involvement through activities like group discussions, case studies, role plays, and problem based projects, which enhance understanding and overall engagement. The study focuses on integrating advanced educational technologies Virtual Reality (VR), Simulation Based Learning, Gamification Based Learning, and Mobile App Based Learning (MAL) within active learning frameworks, particularly in STEM education [2]. These technologies offer opportunities to improve engagement, deepen learning, and develop essential skills for the 21st century. This research examines the technical and design aspects of these strategies, highlighting their potential to transform educational systems and create motivating, participatory learning environments.

This paper investigates the effectiveness of active learning methods in enhancing student motivation in digital learning environments [3]. The study focuses on how Virtual Reality Based Learning, Simulation Based Learning, Gamification Based Learning, and Mobile App Based Learning (MAL) impact student motivation, and how these technologies align with motivational theories like Self Determination Theory (SDT) and Expectancy Theory. SDT suggests that intrinsic motivation is fostered when individual's basic psychological needs autonomy, competence, and relatedness are met. The research highlights how active learning methods can fulfill these needs and increase student engagement and satisfaction [4]. Although prior studies have examined active learning and technology integration, there is a gap in understanding how emerging technologies specifically VR, gamification, and mobile apps can be integrated to effectively enhance motivation and engagement in digital education. This study aims to fill that gap by exploring the synergy of these technologies in motivating students and improving their learning experience [5].

Moreover, active learning methods also tap into students' potential more holistically, allowing them to develop their social, critical and creative skills in a context relevant to real life. Collaborative and reflective activities in active learning strengthen student's understanding of the concepts being taught while enriching their learning experience. This not only creates a more dynamic learning environment, but also prepares students to face the ever changing demands of the real world [6].

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II. Literature Review

This report provides a comprehensive overview of active learning methods and their effectiveness in engaging students in the learning process. It discusses various active learning strategies, including group discussions and problem based projects, which align with the approach described in the paper [7]. This study explores the role of emotion and engagement in the classroom environment. To support these claims, this research draw upon Self Determination Theory (SDT), which posits that individuals are motivated when their basic psychological needs autonomy, competence and relatedness are met [8]. Technologies such as VRL, SL, GL, and MAL are particularly well suited to fulfill these needs. For example, VRL offers immersive experiences that provide students with a sense of competence as they navigate complex virtual environments. Similarly, SL and GL integrate problem solving and interactive rewards that foster a sense of autonomy and mastery [9]. Vroom's Expectancy Theory further supports these interventions by explaining that students are more motivated when they perceive a strong connection between their efforts and the outcomes. which these technologies facilitate by offering instant feedback and personalized learning paths [10]. which are essential factors in maintaining student's interest and passion for learning. it discusses how active learning methods can foster positive emotional experiences and increase student engagement supporting the arguments presented in the paper

This literature review examines the challenges and opportunities associated with teaching online courses in higher education. It discusses the importance of integrating active learning methods into online learning environments to enhance student engagement and motivation, In particular, interdisciplinary studies that focus on the integration of emerging technologies, such as VR and gamification, within active learning frameworks have demonstrated a positive impact on motivation and engagement [11]. Research by Deterding et al. on gamification and its motivational potential in educational settings provides further support for our hypothesis that these technologies can significantly enhance student motivation. Additionally, the application of these technologies in STEM education has been shown to bridge the gap between theoretical knowledge and practical application, an area that this research aims to address by integrating both technology and motivation theory into the educational context.

This study's originality stems from its comprehensive and integrated analysis of Virtual Reality (VR), Simulation Based Learning (SL), Gamification Learning, and Mobile App Based Learning (MAL) within a unified framework to enhance student motivation in the digital era. Critically, few studies provide a synthesized empirical investigation into how these multiple emerging technologies collectively and synergistically influence engagement and motivation, aligning with established motivational theories. This paper addresses this gap by offering a holistic perspective on the potential of integrating these advanced digital learning tools, thereby contributing a novel understanding of their combined efficacy and practical implementation strategies in contemporary educational settings.

III. Method

Education has been a rapidly changing field, especially amidst the technological advancements that have swept through the digital age. Technological innovation has brought a significant impact on the way we learn and teach, opening the door to the development of more dynamic, interactive and relevant learning methods. In this context, the main focus of current educational research is how technology can be effectively used to improve the quality of learning and student engagement [12].

Technologies such as Virtual Reality (VR), computer simulation, gamification, and mobile applications have been in the spotlight in an effort to improve learning effectiveness [13]. Virtual Reality (VR) offers immersive and immersive learning experiences, allowing students to experience things that are hard to reach in real life. Computer simulations allow students to interact with complex situations or scenarios, allowing them to test hypotheses and see the impact of the decisions they make [14].

This study used a quantitative research design to explore the impact of active learning strategies, supported by digital technologies, on student motivation in digital learning environments [15]. A purposive sample of 150 undergraduate students from diverse Indonesian universities was selected to represent those actively using digital learning tools. Data were collected through online surveys with multiple choice and Likert scale questions assessing engagement with Virtual Reality Based Learning (VRL), Simulation Based Learning (SL), Gamification Learning , and Mobile App Based Learning (MAL), as well as self reported motivation [16]. The instrument was pre tested for reliability, achieving a Cronbach's alpha (α $>$0.7), ensuring internal consistency. Qualitative insights were also gathered through observations and open ended survey questions, analyzed via thematic analysis to identify patterns related to motivation and engagement. Triangulation of survey and observation data strengthened the validity of the findings, ensuring the reliability and relevance of the data in understanding the influence of active learning on student motivation in digital contexts [17].

By continuing to explore the potential of these technologies and integrating them into learning practices, we can expand the scope of education and create more engaging, effective and inclusive learning experiences for all students [18].

A. Hypothesis and Variable

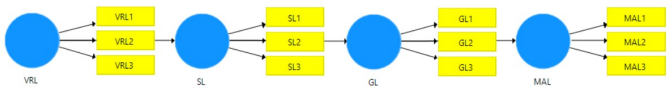

Fig. 1. Concept of the Hypothesis

- Virtual Reality Based Learning (VRL). Improving Understanding of Difficult Concepts: Students who engage in

virtual reality based learning (VRL) will show improvement in the understanding of difficult concepts, as their immersive experience allows for in depth exploration and real world experience.

- Simulation Based Learning (SL). Improves Critical Thinking Skills: Students who engage in simulation based learning will develop better critical thinking skills, as they can test hypotheses, see the impact of decisions, and understand complex concepts better through simulation experiences [19].
- Gamification Based Learning. Increases Student Motivation: Students who engage in gamification based learning will show increased motivation and engagement, as game elements such as scores, levels, and rewards encourage them to achieve learning objectives [20].
- Mobile App Based Learning (MAL). Using mobile applications to deliver interactive learning materials, quizzes, and assignments that can be accessed anywhere and anytime, allowing for adaptive and personalized learning [21].

B. Relationships Between Hypotheses

- Hypothesis 1 (Virtual Reality Based Learning) can relate to Hypothesis 2 (Use of Simulation) as both address the use of technology in learning. The use of Virtual Reality (VRL) and Simulation (SL) can complement each other in improving student's understanding of difficult concepts and critical thinking skills [22].
- Hypothesis 3 (Gamification Based Learning) can also relate to Hypotheses 1 and 2 as gamification can be implemented in Virtual Reality (VRL) and Simulation (SL) environments. Game elements such as scores, levels, and rewards can be applied in both contexts to increase student's learning motivation [23].
- Hypothesis 4 (Mobile App Based Learning) can be related to the previous three hypotheses because mobile applications can be a medium to integrate learning technologies, including Virtual Reality (VRL), Simulation (SL), and Gamification Based Learning. Mobile apps can be used to give students access to interact with learning content flexibly, including the use of game elements in learning [24].

IV. Results and Discussion

The analysis of the collected data reveals a significant contribution of each independent variable Gamification, Simulation Based Learning (SL), and Mobile App Based Learning (MAL) to student motivation. To ensure full transparency, the data analysis rigorously employed regression analysis to examine the relationships between the use of VRL, SL, GL, MAL (independent variables) and student motivation (dependent variable) [25].These values indicate the proportion of variance in student motivation explained by each independent variable [26].

A. Result of R Square

For Gamification Learning, (R^2 value was 0.502, with an Adjusted (R^2 of 0.501. For Mobile App Based Learning (MAL), the (R^2 was 0.487, and the Adjusted (R^2 was 0.486. For Simulation Based Learning (SL), the (R^2 was 0.534, with an Adjusted (R^2 of 0.533. These figures demonstrate a robust fit of the models, indicating that a substantial proportion of the variance in student motivation is explained by these active learning methods. The findings are clearly structured, demonstrating the impact of each active learning method on student motivation [27].

TABLE I
Result of R Square

	R Square	**Adjusted R Square**
GL	0.502	0.501
MAL	0.487	0.486
SL	0.534	0.533

Specifically, the (R^2 values indicate that 50.2% of the variation in learning motivation can be attributed to gamification based learning, 48.7% to mobile app based learning, and 53.4% to simulation based learning. This provides strong empirical evidence that student's active participation in Gamification Learning, MAL, and SL significantly contributes to their overall learning motivation. These results directly support Hypothesis 3, which postulates that Gamification Based Learning increases student motivation, and Hypothesis 4, which suggests that Mobile App Based Learning enhances student engagement. The moderate to strong effects observed for Gamification Learning ((R^2 = 0.502) and MAL ((R^2 = 0.487) are consistent with theoretical frameworks emphasizing that interactive and game based learning environments intrinsically boost student engagement and motivation [28]. Furthermore, these findings align well with Self Determination Theory, which underscores the importance of autonomy, competence, and relatedness in fostering intrinsic motivation within educational settings [29].

B. Virtual Reality Based Learning (VRL)

TABLE II
Brief Explanation of Each Variable of Virtual Reality Based Learning (VRL)

Independent Variable	**Dependent Variable**	**Control Variable**
Virtual Reality Based Learning (VRL)	Understanding of Difficult Concepts: A score or grade that reflects a student's understanding of a difficult concept, measured through a test, project or other assessment.	1. Students Initial Level of Understanding: Students' level of understanding before engaging in learning using VRL.
		2. Student Interest in the Learning Subject: The level of student interest in the learning topic or material presented through the VRL.

		3. Simulation Complexity Level: A variable that measures the level of complexity of the situation or problem being simulated in learning.
		4. Instructional Support: A score reflecting the level of support provided by the instructor in implementing simulation-based learning.

In table II the explanation of each variable of Virtual Reality Based Learning (VRL) is provided. The independent variable, in this case, is VRL, which refers to the level of student participation in virtual reality based learning activities [30]. It measures how actively students engage and interact with the learning content presented through VR technology. The dependent variable, concept understanding, reflects how well students understand difficult concepts in the learning process [31]. This is assessed through students' completion of tasks, projects, or other assignments designed to measure their grasp of the concepts [32].

Additionally, the control variables, which include several factors that may influence the relationship between the independent and dependent variables, are also considered [33]. These factors include students' initial level of understanding, the learning environment and the level of instructional support provided by teachers or instructors in implementing VRL. All these variables interact to determine the effectiveness of VRL based learning [34].

C. Simulation Based Learning

TABLE III
BRIEF EXPLANATION OF EACH SIMULATION BASED LEARNING (SL) VARIABLE

Independent Variable	**Dependent Variable**	**Control Variable**
Simulation Based Learning (SL)	A score or value that reflects the level of students' critical thinking skills, measured through observation, project assessment, or tests designed to measure aspects of critical thinking skills such as analysis, evaluation, and synthesis of information.	1. Students' Initial Level of Understanding: A score or value that reflects students' initial level of understanding before engaging in learning using simulation.
		2. Student Interest in the Learning Subject: A score or value that reflects students' interest in the learning topic or material presented through the simulation.
		3. Simulation Complexity Level: A variable that measures the level of complexity of the situation or problem being simulated in learning.
		4. Instructional Support: A score reflecting the level of support provided by the instructor in implementing simulation-based learning.

In table III the independent variable is the level of students' initial understanding, which includes their foundational knowledge of the subject matter, critical thinking skills, and their ability to solve complex problems. This variable is essential because it affects how well students can engage with simulations, which often require them to apply theoretical knowledge to practical scenarios. Students with a higher initial understanding are likely to approach the simulation with more confidence, leading to a more immersive and productive learning experience. The dependent variable refers to the students' level of engagement, which can be observed through their participation in the simulation, their interaction with the learning tasks, and their ability to solve problems presented in the simulation. Active engagement is a key indicator of successful learning in this model. The control variables include the students' interest in the learning subject, which can either enhance or diminish their motivation to participate fully in the simulation. A higher level of interest typically correlates with higher engagement. Additionally, the instructional support provided by the teacher plays a pivotal role, as it can guide students through the complexities of the simulation and provide necessary scaffolding to ensure they are progressing in the right direction. The complexity of the simulation itself is another crucial factor; simulations that are too simplistic may fail to challenge students, while overly complex simulations may overwhelm them. Striking the right balance in simulation difficulty is essential for optimizing the learning experience.

D. Gamification Based Learning

TABLE IV
BRIEF EXPLANATION OF EACH GAMIFICATION BASED LEARNING (GL) VARIABLE

Independent Variable	**Dependent Variable**	**Control Variable**
Gamification Based Learning (GL)	Learning Motivation: A score or value that reflects a student's level of learning motivation, measured through surveys, questionnaires, or behavioral observations, which includes aspects such as interest in learning materials, desire to achieve goals, and level of engagement in learning.	1. Gamification Design Quality: Variables that measure the quality of gamification design, including clarity of objectives, relevance to learning materials, and fairness in rewarding.
		2. Student Interest in the Learning Subject: A score or value that reflects students' interest in the learning topic or material presented through gamification.
		3. Instructional Support: A score or value that reflects the level of support provided by the instructor or teacher in implementing gamification-based learning.
		4. Learning Environment: A binary variable that indicates whether the learning environment supports or does not support the implementation of gami-

		fication-based learning, such as the availability of technology or facilities needed.

In table IV the independent variable revolves around the design of the gamified elements used within the learning environment. These elements can include game mechanics such as points, rewards, leaderboards, levels, and challenges that incentivize students to participate more actively in the learning process. The goal is to transform the learning experience into an engaging, game like environment that motivates students to take an active role in their education. The quality of the gamified content directly influences the level of student engagement, as well designed games can increase intrinsic motivation by making the learning process more enjoyable and rewarding. The dependent variable is the students' interest and motivation towards the learning subject, which is influenced by the appeal of the game mechanics and how effectively they resonate with students. When students find the game engaging, they are more likely to invest time and effort into learning, leading to better retention of the material and a more positive learning experience. The control variables in this context include instructional support, which refers to the guidance provided by the instructor to help students navigate the gamified learning experience and ensure that learning objectives are met. It also includes the learning environment, which considers whether the physical or digital space where the gamification takes place is conducive to effective learning. A well designed learning environment can enhance the gamified elements by providing an atmosphere that encourages exploration, collaboration, and deeper engagement with the material.

E. Mobile App Based Learning (MAL)

TABLE V
BRIEF EXPLANATION OF EACH MOBILE APP BASED LEARNING (MAL) VARIABLE

Independent Variable	**Dependent Variable**	**Control Variable**
Mobile App Based Learning (MAL)	Learning Motivation: A score or value that reflects a student's level of learning motivation, measured through surveys, questionnaires, or behavioral observations, which includes aspects such as interest in learning materials, desire to achieve goals, and level of engagement in learning.	1. Mobile App Quality: A variable that measures the quality of mobile apps used in learning, including the availability of interactive features, clarity of the user interface, and suitability to student needs.
		2. Internet Access Availability: A binary variable indicating whether students have stable and sufficient internet access to use mobile applications in learning.
		3. Instructional Support: A score or value that reflects the level of support provided by the instructor or teacher in using the mobile app as part of he learning process.
		4. Learning Environment: A binary variable indicating whether the learning environment supports or does not support the use of mobile apps in learning, such as the availability of mobile devices or school policies regarding the use of technology.

In table V the independent variable focuses on the quality and usability of the mobile application used in the learning process. The design and features of the app, such as its user interface, the ease of navigation, and the availability of interactive content, significantly influence how students interact with the app and engage in learning. The app's ability to present information in an accessible, clear, and interactive format is crucial for enhancing student learning outcomes. Features like notifications, gamified elements, and personalized learning paths can increase the app's effectiveness. The dependent variable is the level of student engagement with the mobile app, which can be observed through their frequency of use, the amount of time spent on tasks, and the quality of their interaction with the content.Students who engage more actively with the app are likely to experience better learning outcomes, as their consistent use fosters a deeper understanding of the subject. The control variables in this model include mobile access availability, which looks at whether students have access to the necessary devices and internet connection to fully engage with the mobile app. In areas with limited access, this variable can be a significant barrier to effective learning. Instructional support is another important control factor, as it ensures that teachers provide adequate guidance for students to use the mobile app effectively, addressing any technical issues and helping them navigate the app's features. Lastly, the learning environment is also a control variable, which looks at how conducive the physical or digital environment is to using the mobile app. Factors like the availability of quiet study spaces, the compatibility of the app with various devices, and the presence of technical support all contribute to how well students can engage with the mobile app and how successful the learning experience is. These versions are now more detailed and provide a deeper context to each of the variables, while still mentioning the corresponding tables.

V. CONCLUSION

This study concludes that the integration of active learning technologies is a robust and effective strategy for significantly enhancing student motivation in STEM education. The quantitative analysis confirms that Simulation Based Learning (SL), Gamification Learning (GL), and Mobile App Based Learning (MAL) are substantial predictors of variance in student motivation. The findings demonstrated a strong positive impact, with SL explaining 53.4%, GL 50.2%, and MAL 48.7% of the variance in learning motivation, respectively. This empirical

evidence validates that interactive pedagogical tools are not merely supplementary but are powerful drivers of engagement, aligning with motivational frameworks like Self Determination Theory by fulfilling students' intrinsic needs for autonomy, competence, and relatedness. Moreover, the primary novelty of this research is its comprehensive and integrated investigation of four distinct technologies Virtual Reality (VR), SL, GL, and MAL within a single, unified framework. While previous studies often examined these tools in isolation, this paper provides a synthesized empirical analysis that highlights their collective and synergistic influence on student motivation.

For future work, it is recommended that active learning methodologies be integrated as a core component of the curriculum rather than treated as ancillary. To maximize effectiveness, educational activities should be tailored to meet the diverse learning needs of students, ensuring inclusivity and engagement. Additionally, educators should adopt a dynamic approach by continuously monitoring student responses and adapting their strategies accordingly.

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